NOAA Coastal Ocean Program

Phase II Research

FY 1999 Principal Investigators' Reports

National Oceanic and Atmospheric Administration
Pacific Marine Environmental Laboratory
7600 Sand Point Way NE
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CONTENTS

TITLE: Circulation modeling for the Southeast Bering Sea

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PROGRESS

As part of the Southeastern Bering Sea Carrying Capacity program (SEBSCC) we have continued our development of a primitive equation circulation model of the Southeast Bering Sea shelf and basin which includes both tidal and subtidal dynamics. Physical simulations are used to explore the relative impact of winds, tides and heat flux in different years, and investigate how these affect the fate of walleye pollock spawned in different regions of the Southeastern Bering Sea.

Primary physical features of the Southeast Bering Sea include: tides and tidal mixing, flow through straits, shelf-slope exchange, meanders and eddies, ice physics and the cold pool. Our free-surface, primitive equation circulation model is based on the S-Coordinate Rutgers University model (Song and Haidvogel, 1994), and is implemented at 4-km horizontal resolution with 20 vertical levels. Surface forcing is provided by daily NCEP winds and heat fluxes.

Horizontal boundary forcing includes measured and modeled subtidal currents and five tidal components (M2, S2, N2, K1, and O1) derived from a global implementation of the Spectral Element Ocean Model (Haidvogel et al., 1996). Boundary forcing is achieved by separately nudging tidal components at the outer edge of the (telescoped) regional model domain, and subtidal flows further within (but still external to the finely resolved southeastern Bering Sea). In principle the tidal dynamics will pass cleanly through areas of subtidal nudging without interference.

A substantial component of heat and buoyancy fluxes at the surface of the Southeastern Bering Sea is due to ice melt. This exerts a profound effect on the heat and salt content of the shelf waters, their density stratification and their vertical mixing. A persistent pool of cold water is formed on the shelf in some years due to the influence of ice in the winter and spring. A full model of ice thermodynamics and advection was beyond the scope of this project. Instead, in FY99 we developed an algorithm for ice forcing based on the observed phenomenon of ice being advected south into the Southeast Bering Sea and subsequently melting there (Stabeno et al. 1999). We treat ice as a forcing variable and compute daily ice melt based on ice coverage from data, and the surface temperature computed in the circulation model relative to the temperature of the ice (assumed to be -1.7 degrees C). Melt rates were calibrated using temperature data from mid-shelf mooring S2 (also called M2). We used ice pack data at 1/4-degree resolution from the National Ice Center, and digitized maps of ice coverage from the National Weather Service in Anchorage to the same grid. Computed heat and buoyancy fluxes based on this algorithm are added at the surface of the circulation model at each model time step.

SCIENTIFIC ACCOMPLISHMENTS

In FY98 we had compared two recent years (1995 versus 1997), based on their radically different physical and biological character and the availability of field data. In FY99 we compared these two years using the newer version of the model which includes ice melt forcing, and began sensitivity experiments to address the relative impact of wind, tidal and buoyancy forcing. We improved our tidal forcing, and developed new techniques for visualizing model output, as described below.

The model reproduces many of the major features in the southeastern Bering Sea; in particular, a sluggish circulation on the inner shelf, a vigorous alongshelf flow at the shelf break, anticyclonic flows around the Pribilof Islands (partly the result of tidal residual currents), and colder temperatures on the shelf than in the deep basin. A large degree of mesoscale eddy activity (typically ~50-km diameter) is produced, with free surface height signatures (~5cm) similar to those observed in altimetric data.

In significant portions of the southeastern Bering Sea, the tidal velocities account for greater than 95% of the Total Kinetic Energy in current meter records. One might expect that vertical mixing would be uniformly strong in regions of high tidal energy. However, a rendering of instantaneous vertical viscosity computed from the model suggests that this is not the case; highest values are instead produced along the 100-m isobath (where strong subtidal flows were generated) and along the shelf break (where both tidal and subtidal velocities are strong). Apparently the subtidal velocities contribute strongly to the overall mixing pattern.

Initial runs of the model did not attempt a specific phasing of the tidal components relative to a particular year, but did include relative phase information in space. It has been suggested that the phasing of the tides relative to one another in time can have important effects on the seasonal pattern of mixing, and should itself exhibit interannual variability. That is, in some years the interactions of the many tidal components will lead to especially large tidal velocities, and hence more mixing in particular months or even on specific days or times of day. However, comparative runs for one month show little difference between a run with random tidal phases, versus one with tides phased specifically for year 1995.

Our runs for 1995 versus 1997 exhibit significant differences in both velocity and temperature fields (Fig.Herm- 1, Fig.Herm- 2). First, 1997 is much warmer than 1995, due largely to the greater penetration of ice in 1995. Second, mesoscale eddy activity is much greater in 1995 than 1997. We speculate that this result derives from two other features distinguishing the two years: stronger North Aleutian Slope Flow in 1995 and more ice in 1995. The former provides more mean kinetic energy to the shelf break, and the latter strengthens the temperature gradient (and hence the Available Potential Energy) on the shelf. Both should lead to greater formation of eddies. To demonstrate how this enhanced eddy activity might affect spawned walleye pollock in the Bering Sea, we conducted a simple float tracking experiment using depth-averaged velocities (includes tides). Floats released near the shelf break in 1995 show a greater tendency to wander off into the deep basin, relative to their equivalents in 1997.

We have compared depth-time profiles from the model with equivalent profiles from moored thermistor chains at two cross-shelf locations (60 and 120-m depths, respectively). In both data and model, a significantly warmer water column is observed in 1997 than in 1995. Also, in both data and model the profiles at the deeper location are significantly warmer than those at the shallower site. The model reproduces some specific daily events seen in the data as well (Fig. Herm-3).

In FY99 we have also developed advanced visualization techniques for Bering Sea model output, through use of the Virtual Reality Modeling Language standard. With support from NOAA, we have demonstrated effective techniques for immersive visualization of SEBSCC model data,

using low-cost personal computers (see **http://www.pmel.noaa.gov/~hermann/sebscc.html** and **http://www.pmel.noaa.gov/~hermann/vrml/stereo.html)**.

APPLICATIONS

Hermann, A. J. and D. B. Haidvogel, "An open boundary technique for the simultaneous modeling of tidal and subtidal dynamics in the coastal Gulf of Alaska and the Bering Sea". International conference on coastal ocean and semi-enclosed seas: circulation and ecology modeling and monitoring. Moscow, Russia, 8-12 September 1998. (Extended abstract in press)

Hermann, A. J., D. B. Haidvogel (presenter), E. L. Dobbins, P. J. Stabeno, and D. Musgrave. "Simulation of the Southeastern Bering Sea and Gulf of Alaska Using Coupled Regional/Basin-Scale Models", Sigma Coordinate Ocean Model Users Meeting, Bar Harbor, ME, 20-22 September 1999.

Hermann, A. J., D. B. Haidvogel, P. J. Stabeno, S. Hinckley and D. Musgrave. "Interannual modeling of tidal and subtidal dynamics on the Southeastern Bering Sea shelf". North Pacific Marine Science Organization (PICES) 8th annual meeting, Vladivostok, Russia, 8-17 October 1999.

Bering Sea model results home page, with sample output from model runs (including animations and virtual worlds): **http://www.pmel.noaa.gov/~hermann/sebscc.html**

STEPS TO COMPLETION

The considerable computer time (and related expense) of running the numerical model has been an impediment to completion of this project. It has also become apparent from SEBSCC field observations that a larger model domain is necessary to capture the paths of pollock through the juvenile stage. One possibility is to revive the coarser, rigid-lid circulation model developed earlier in the program (which covered the entire eastern Bering Sea), and drive it with the realistic wind data now available for the fine-scale model. This would preclude realistic tidal dynamics and will not resolve eddies; however it may provide mean flows useful for the individual-based pollock model and higher trophic levels.

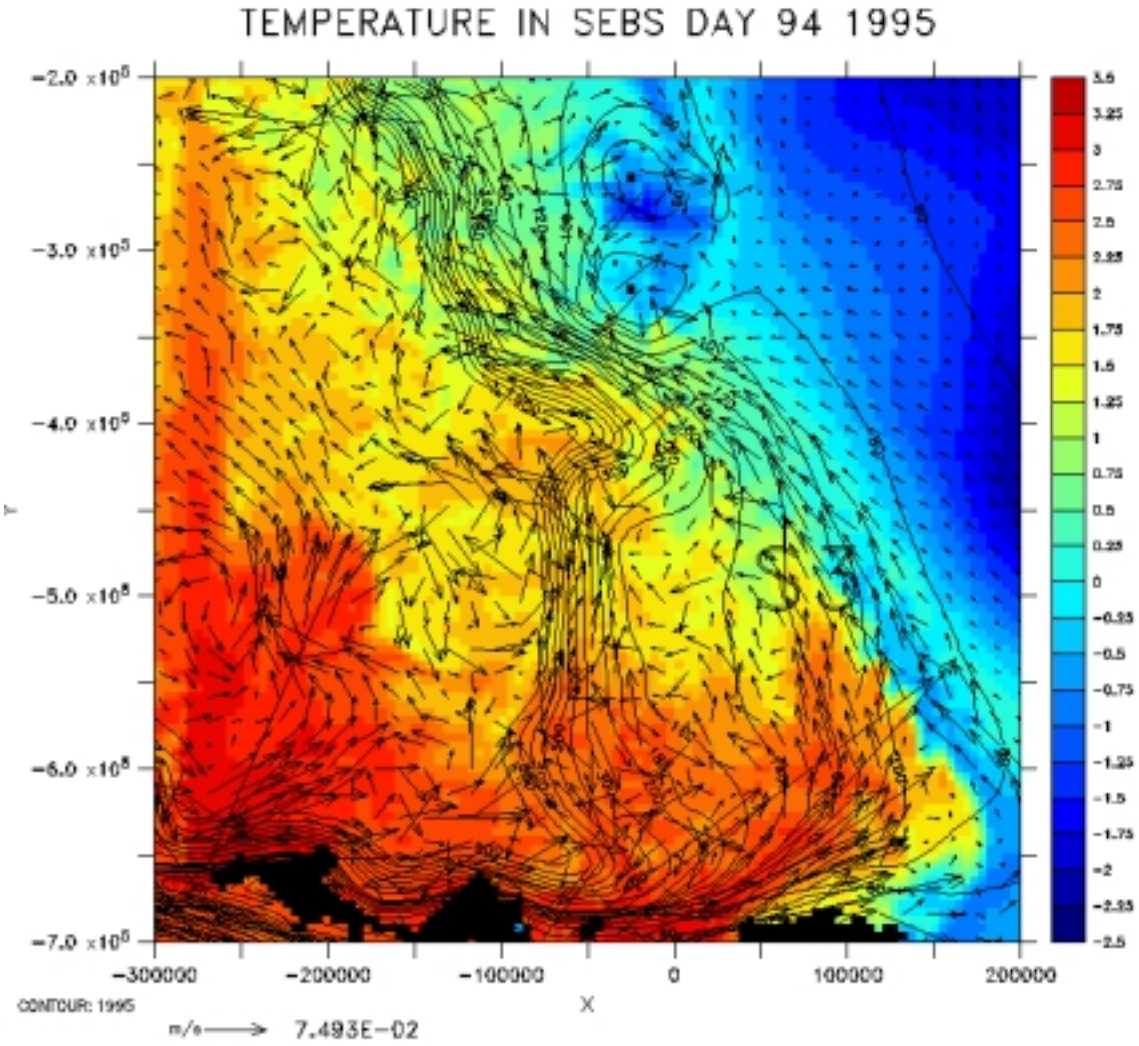

Figure Herm-1. Regional model output for 1995. Temperature is shown shaded in degrees C; distance on x and y axes are indicated in meters. Location of Station 3 (S3) is marked. Only every third velocity vector is plotted; full resolution of the model is 4 km. Note the penetration of warmer water from the south, and the pool of colder water on the shelf. The two Pribilof Islands are marked as small black squares.

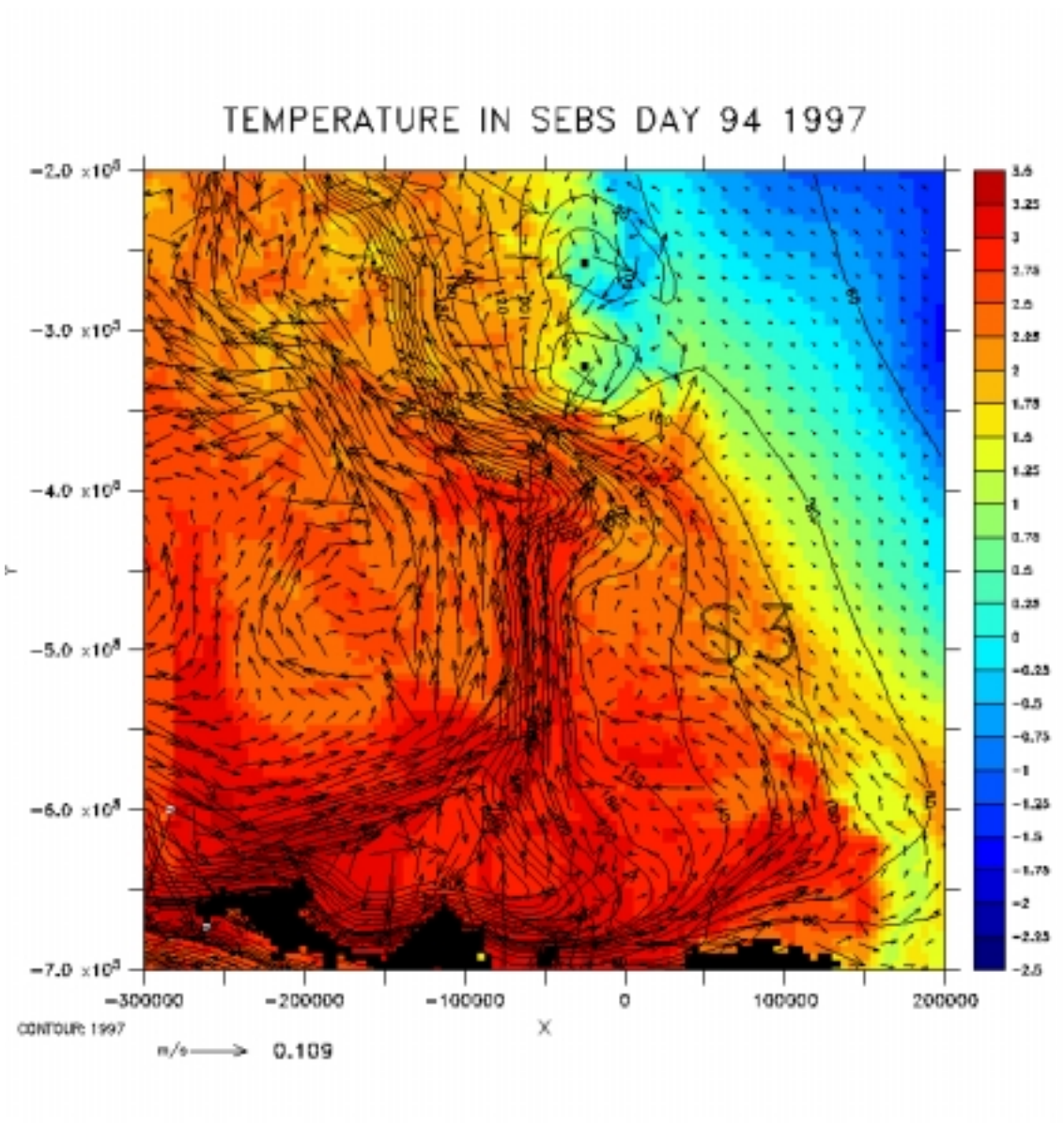

Figure Herm-2. Regional model output for 1997.

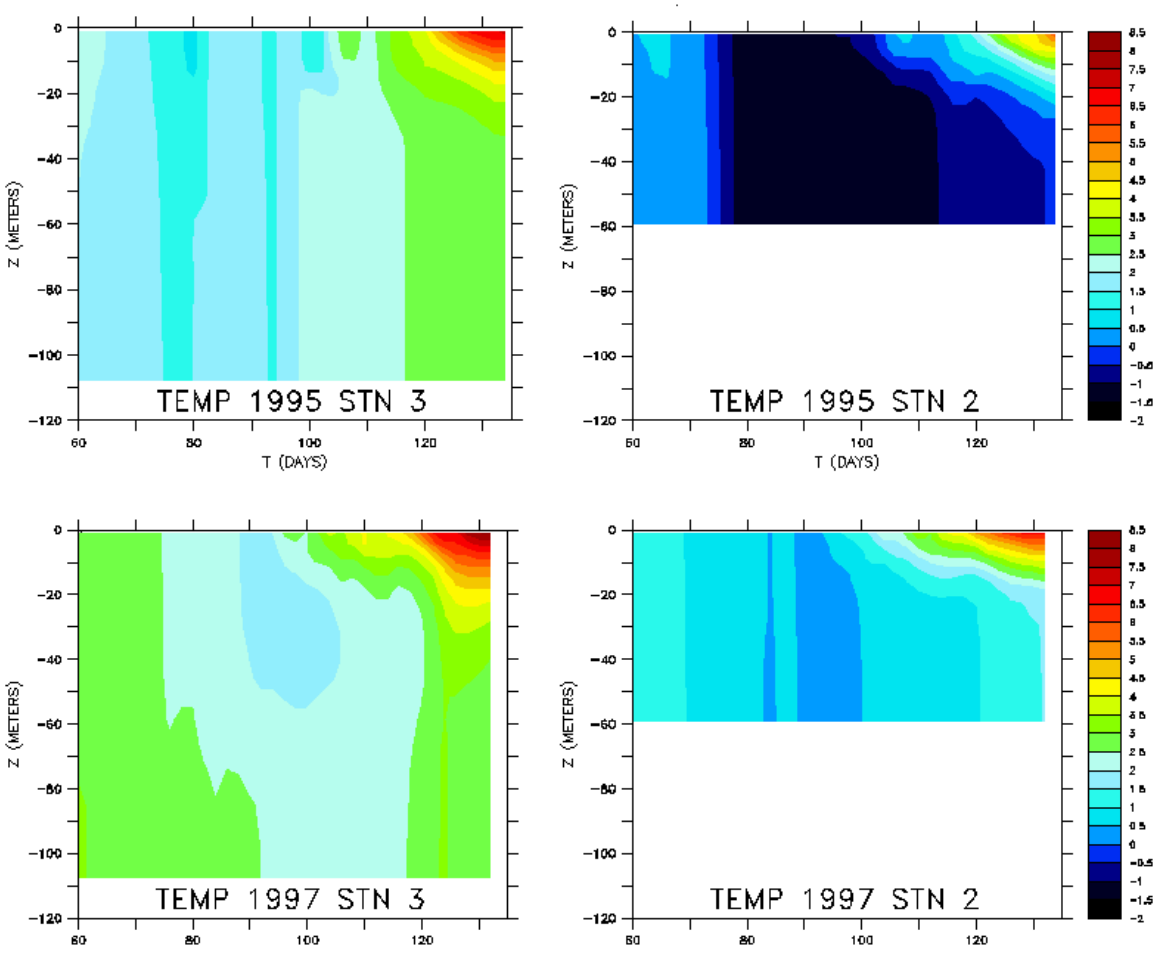

Figure Herm-3. Cross-shelf temperature profiles from model output. Temperature is shown shaded in degrees C. Locations of Stations 2 and 3 (S2, S3) are indicated. Note the colder temperatures produced on the shelf, and the warmer temperatures exhibited for 1997 relative to 1995.

TITLE: Measures of ecosystem trends in the southeastern Bering Sea

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PROGRESS

The goal of this component is to synthesize knowledge of the southeastern Bering Sea ecosystem. The specific objectives are to: (1) develop time series of biophysical indices of the ecosystem, (2) establish baseline conditions and examine patterns in these series, and (3) propose biophysical processes that link indices. This research provides products that characterize the southeastern Bering Sea and thereby increases understanding of this rich ecosystem. The products, consisting of both environmental time series and publications will be made available to other SEBSCC investigators, the wider scientific community and to those responsible for management.

During FY99, time series of mixing indices and sea ice extend were produced and the development of waters property characteristics over the middle shelf is ongoing. As the series were examined, it became apparent that developing a “base-line” condition for any given parameter is limited by the duration of many of the series. This is of particular importance since regime shifts with decadal periods likely are dominant features of the regional biophysics. Data sets such as ice extent as inferred from satellite data barely span more than the present regime. Direct time series analysis may be of limited interpretation. This component also endeavors to synthesize research conducted by other SEBSCC components and other Investigators, and several products resulted from this effort (see below).

SCIENTIFIC ACCOMPLISHMENTS

In order to visualize pathways through which changes in climatic influence the biological environment, the model used for the North Pacific Ocean (Francis et al., 1998: Effects of interdecadal climate variability on the oceanic ecosystems of the NE pacific. *Fish. Oceanogr.*, *7*:1-21.) was adapted to the Bering Sea (Figure Schu-1). Ice was added to include the coupling between atmospheric phenomenon and ocean that effect biota in a bottom-up mode. The presence of ice also directly influences distributions of marine mammals exerting an aspect of top-down control. Note that the presence of a coccolithophorid bloom also has direct influence on light penetration (primary production) and success of visual feeders.

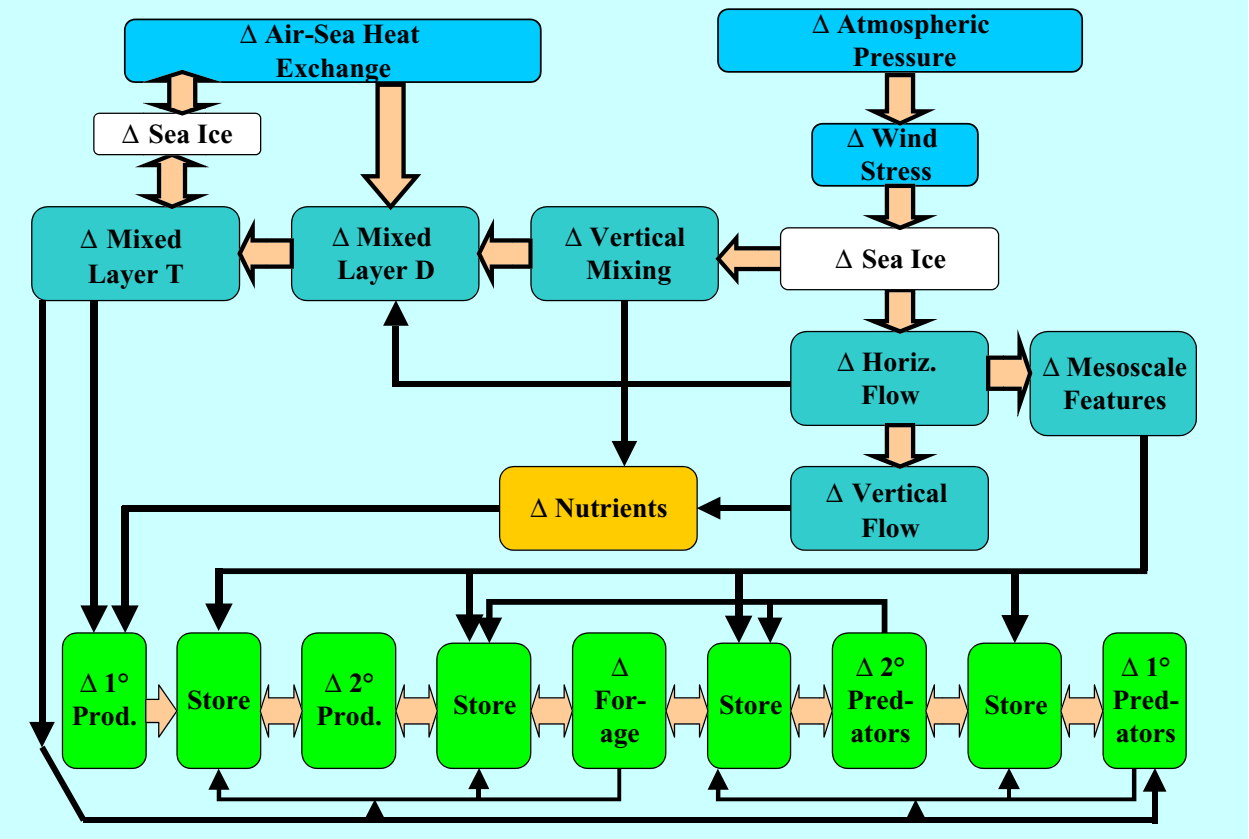

Figure Schu-1. Mechanistic pathways from changes in climate to marine biota (after Francis et al., 1998).

This model was useful in examination of possible causes of dramatic changes in medusae biomass in the eastern Bering Sea (Brodeur et al., in press). The time series of medusae biomass shows a gradual increase from 1979 to 1989, followed by a dramatic increase in the 1990s. The median biomass increased ten-fold between the period 1982-89 and 1990-97. The majority of

this increase occurred within the Middle Shelf Domain. Whether this marked increase in biomass of gelatinous zooplankton resulted from anthropogenic perturbation of the environment or is a manifestation of natural ecosystem change is unclear. Indices of several large-scale winter/spring atmospheric and oceanographic features (extent and duration of sea ice) in the Bering Sea, however, exhibited concomitant changes beginning around 1990, indicating that a possible regime change occurred at this time.

It is clear that climate change influence marine ecosystems through changes in weather patterns (e.g., Hunt et al., submitted). Thus, examination of the interactions between weather and physical/biological processes in the ocean provides information relevant for understanding and predicting potential impact of global change on the Bering Sea. Due to unusual weather patterns in both 1997 and 1998, physical and biological conditions of the southeastern Bering Sea differed greatly from what was expected. In 1997, there was ice present until April, an ice-related bloom with drawdown of nutrients, and a mixing event in mid-May that renewed production. Unusually warm, calm weather and deep depletion of nutrients followed. Subsequently the first-documented Bering Sea coccolithophorid bloom and a short-tailed shearwater (*Puffinus tenuirostris*) die-off occurred. In 1998, sea ice was present briefly in February, and storms following ice retreat prevented a strong thermocline until late June. Rather than a short pulse, production was moderate and consistent from May through June. The coccolithophorid bloom was still present, apparently having over-wintered. Although shearwaters were again malnourished, no unusual mortality was found. In both 1997 and 1998, adult euphausiids (*Thysanoessa raschii*), a primary food of shearwaters, had densities over the inner shelf one to two orders of magnitude lower than in the period 1972-1982; copepod densities were one to two orders of magnitude higher than previously reported.

APPLICATIONS

Publications

Brodeur, R.D., C.E. Mills, J.E. Overland, G.E. Walters, and J.D. Schumacher. In press, Evidence for a substantial increase in jellyfish in the Bering Sea, with possible links to climate change. *Fish. Oceanogr. 9(1).*

Hunt, Jr. G.L., C. L. Baduini, R. D. Brodeur, K. O. Coyle, J. M. Napp, J. D. Schumacher, P. J. Stabeno, D. A. Stockwell, T. E. Whitledge, and S. I. Zeeman. Ecosystem Responses of the Southeastern Bering Sea to Abnormal Weather Patterns in 1997 and 1998. Submitted, ICES CM 1999/O: 06 Global Change Aspects.

Schumacher, J.D., in preparation. Regime shift theory: Review of changing environmental conditions in the Bering Sea and Eastern North Pacific. *In:* Proc. Fifth N. Pac. Rim Fisheries Conf.

Schumacher, J.D., N.A. Bond, R.D. Brodeur, P.A. Livingston, J.M. Napp and P.J. Stabeno, in preparation. Climate Change in the Southeastern Bering Sea and Some Potential Consequences for Biota. *In:* Hempel and Sherman (Eds.) Large Marine Ecosystems of the World - trends in exploitation, protection and research.

Stabeno, P.J., N.A. Bond, N.B. Kachel, S.A. Salo, J.D. Schumacher. Temporal Variability in the Physical Environment over the Southeastern Bering Sea. In press, *Fish. Oceanogr.*

Presentations at Scientific Meetings

February 1999 - Are recent eastern Bering Sea ecosystem anomalies early evidence for climate change? What do records of zooplankton biomass and species composition tell us? American Society of Limnology and Oceanography meeting, Santa Fe, NM, (Napp, J.M., Brodeur, R.D., Schumacher, J.D., Stabeno, P.J., and Jorgensen, E.M).

March 1999 – Changes in the Physical Environment of the Eastern Bering Sea and Some Potential Consequences for Biota. ADF&G workshop on Ocean-Climate Change and Variability if Fish Recruitment, 10-12 March, Anchorage, AK. (Schumacher, J.D., N.A. Bond, R.D. Brodeur, P.A. Livingston, J.M. Napp and P.J. Stabeno)

March 1999 - Apparent nutrient/phytoplankton responses to unusual physical conditions in the Southeast Bering Sea during 1997-1998. Bering Sea Ecoregion Based Conservation Experts Workshop, March 21-23, 1999, Alyeska Prince Hotel, Girdwood Alaska. (Napp, J.M., R.D. Brodeur, J.D. Schumacher, P.J. Stabeno, and E.M. Jorgensen).

STEPS TO COMPLETION

Given the timing of funding during FY99, MILESTONES will be approximately 6 months later than originally proposed. Further, the emphasis is now more on synthesizing results from other research using the pathway model.

TITLE: The regime shift of the 1970's in the southeastern Bering Sea: Detailed analysis of the air-sea interactions crucial to walleye pollock

PRINCIPAL INVESTIGATOR: N.A. Bond, University of Washington/JISAO

CO-PRINCIPAL INVESTIGATOR: N.B. Kachel, University of Washington/JISAO

PROJECT DESCRIPTION

Our work will commence in October 1999 and will build upon the results from our previous SEBSCC-sponsored research (Niebauer et al.). In particular, we will document the changes seen in both the cool and warm seasons during the mid-late 1970's, with a focus on conditions during the spring and summer. This work will use atmospheric data from the NCEP/NCAR Reanalysis and CTD data organized during the previous project. The goal is to determine whether it is possible to estimate the thermodynamic and kinematic properties of Bering Sea shelf waters from the atmospheric forcing. In this endeavor, we will search for analogs to the 1970's in recent times, for which high quality mooring data is available, and hence reasonably good measures of the conditions on the shelf. This work will be closely tied with the study by Kendall and Kim to allow us to concentrate on the locations and elements of the physical environment most crucial to pollock. For example, we plan to try to estimate the cross-shore transports on the shelf and see how well they are correlated with larval abundance and distributions, and to evaluate the atmospheric forcing of cross-slope fluxes at the "green belt" along the shelf break of the Bering Sea. In general, we will also interact closely with other SEBSCC investigators, notably P. Stabeno at PMEL, and communicate our results at forums such as PICES annual meetings.

TITLE: Environmental influences on the early life stages of walleye pollock, *Theragra chalcogramma*, in the southeastern Bering Sea during the late 1970s climate regime shift

PRINCIPAL INVESTIGATORS: Dr. A. W. Kendall, Jr.

COLLABORATORS: Suam Kim, S. Kang, Deborah Blood and William Rugen

PROGRESS

This project is slated for funding beginning in FY2000, thus to date only minimal discussions regarding implementing our plans have been held. Once funds have been received, Dr. Kim and Ms. Kang will travel from Korea to Seattle for training and discussions on implementing the research plan. At that time they will also make ready for shipment to Korea samples of pollock eggs and larvae to be analyzed as part of this project.

SCIENTIFIC ACCOMPLISHMENTS

Plans have been made for implementation of our research plans.

APPLICATIONS

No applications have resulted from this effort yet.

STEPS TO COMPLETION

The start of work on this project will depend on receiving FY2000 funds from the Coastal Ocean Program, and providing these funds to Dr. Kim at the Korea Ocean Research and Development Institute.

TITLE: Monitoring and use of biophysical indices of the southeastern Bering Sea: phase II

PRINCIPAL INVESTIGATORS: J. D. Schumacher, P. J. Stabeno, R. Brodeur, J. M. Napp and G. L. Hunt

PROGRESS

Our goal is to monitor changes in the southeastern Bering Sea ecosystem and gather more information on identified indices, which we will use to characterize this system. Our field season began in February when we deployed a mooring at Site 2. We failed to recover the mooring that had been deployed the previous September due to extensive ice. In May, we recovered both the February and the September moorings and deployed the surface platform. Finally at the end of September we recovered the surface mooring and have deployed a subsurface mooring to measure changes in the winter water column structure and fluorescence. One mooring apparently failed and we lost the acoustic Doppler profiler at site 2. This is a major loss to the program and will effect our ability to measure currents at this location. In addition to the mooring work we conducted a shipboard measurements along the standard CTD grid. Some of this data is now available on the web; the data collected during September will be processed in October and presented at the November PI meeting.

In sharp contrast to 1997 and 1998, water column temperatures were below average, with ice lingering over the southeastern shelf into June. If, as some scientists believe, the Bering Sea has undergone a regime shift, this data will be invaluable in characterizing and understanding the implications of these changes on the ecosystem. It is interesting to note that the large coccolithophorid bloom of 1997 and 1998 has persisted and is as extensive as was observed in the earlier two years.

PUBLICATIONS

Hunt, G.L., C.L. Baduini, R.D. Brodeur, K.O. Coyle, N.B. Kachel, J.M. Napp, S.A. Salo, J.D. Schumacher, P.J. Stabeno, D.A. Stockwell, T.E. Whitledge, and S.I. Zeeman (1999): The Bering Sea in 1998: A second consecutive year of extreme weather-forced anomalies. Eos Trans. AGU [In press].

Napp, J. M. and G. L. Hunt. Anomalous conditions in the southeastern Bering Sea, 1997: Linkages among climate, weather, ocean and biology Fisheries Oceanography. Accepted.

Napp, J.M., A.W. Kendall Jr., and J.D. Schumacher (1998): Biophysical processes relevant to recruitment dynamics of walleye pollock (Theragra chalcogramma) in the eastern Bering Sea. Fish. Oceanogr.

Schumacher, J.D., P.J. Stabeno, N.A. Bond, and J.M. Napp (1999): Ecosystem anomalies in the eastern Bering Sea during 1997. NPAFC Workshop [In press].

Stabeno, P.J. (1998): The status of the Bering Sea in the second half of 1997. PICES Press, 6(2), July 1998, 8–9, 29.

Stabeno, P.J. (1999): The status of the Bering Sea during the last 8 months of 1998. PICES Press, 7(1), 6–8.

Stabeno, P.J., N.A. Bond, N.B. Kachel, S.A. Salo, and J.D. Schumacher (1999): On the temporal variability of the physical environment over the southeastern Bering Sea. Fish. Oceanogr. [In press].

Stabeno, P.J., and P. van Meurs (1999): Evidence of episodic on-shelf flow in the southeastern Bering Sea. J. Geophys. Res. [In press].

STEPS TO COMPLETION

We are on schedule in the timetable presented in the proposal, with exception of the loss of currents during winter of 1998/1999 due to loss of equipment.

TITLE: Currents and transfer processes between shelf and slope waters: a Lagrangian perspective

PRINCIPAL INVESTIGATOR: Phyllis Stabeno, PMEL

PROGRESS

Our goal is to monitor changes in cross shelf advection and currents using satellite-tracked drifters during 1999. SEBSCC supplied 9 satellite-tracked drifters; another 4 were provided funding from Arctic Research Initiative; and one drifter by funding from FOCI. All drifter trajectories are presented herein and in figure (http://corona.pmel.noaa.gov/~stabeno/drifters99). We deployed four drifters in April, five drifters in May, one in June and three drifters in September. One drifter failed to transmit on board ship and thus was not deployed. Two drifters were picked up by fishing boats; two others went aground after several months; the others continue to provide information on currents.

In general, the flow this year was very weak on the shelf, with little cross shelf transport through July. In August the strength of the northeastward flow along the 50-m isobath on the shelf increased. There also was weak flow along the 100-m isobath as revealed by drifters deployed in the vicinity of Unimak Pass. This weak flow is unexpected, since drifters deployed during the last decade all revealed a persistent northwestward flow along this isobath.

At the slope edge, the Bering Slope Current (BSC) appeared weaker than it has been in the last two years and this is supported by hydrographic data which reveal a reduction by over 50% in transport in the Aleutian North Slope Current and the BSC. Several eddies are apparent In the trajectories of the drifters, including a large eddy (diameter ~100km) south-southeast of Pribilof Islands. Such eddies have been observed before and comparison to satellite data (SeaWiFs, altimetry, AVHRR) will be used, if possible, to characterize productivity, and strength of the eddy.

PUBLICATIONS

Stabeno, P.J., and P. van Meurs (1999): Evidence of episodic on-shelf flow in the southeastern Bering Sea. J. Geophys. Res. [In press].

Stabeno, P.J., N.A. Bond, N.B. Kachel, S.A. Salo, and J.D. Schumacher (1999): On the temporal variability of the physical environment over the southeastern Bering Sea. Fish. Oceanogr. [In press].

STEPS TO COMPLETION

Most of the drifters continue to transmit and those deployed in September should give us information of the fall/winter currents at the shelf break and outer shelf. The drifter trajectories will be updated on web location monthly. Analysis and comparison of this year's trajectories to previous years will be undertaken in the next months, but this is an ongoing project as data continues to be collected. Data from the drifter which measured chlorophyll will be not be processed until the drifter stops transmitting (probably November).

TITLE: Origin and physical/biological dynamics of nutrients

PRINCIPAL INVESTIGATOR

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GOAL

The goal of this research is to determine:

1. the source and distributions of nutrients with respect to physical processes.
2. the effect of nutrient availability rates and pathways on primary production processes.

PROGRESS

Water samples were collected on several cruises listed below for:

1. Nitrate plus nitrite	-both fresh and frozen samples
2. Nitrite	-both fresh and frozen samples
3. Ammonium	-both fresh and frozen samples
4. Phosphate	-both fresh and frozen samples
5. Silicate	-both fresh and frozen samples
6. Urea	-productivity frozen samples
7. Dissolved Organic N	-selected hydro and productivity frozen samples
8. Chl/HPLC Pigments	-selected depths on hydro and prod samples

SEBSCC Sampling Cruises:

MF 99-01	Feb 99	Miller Freeman	frozen hydrography
MF 99-06	May 99	Miller Freeman	fresh hydro and productivity
MF 99-12	Sept 99	Miller Freeman	frozen hydrography

Other Cooperative Program: Bering Sea Inner Front Studies

AH 99-220	June 99	Alpha Helix	fresh hydro and productivity
AH 99-222	Aug-Sept 99	Alpha Helix	fresh hydro and productivity

All milestones were accomplished to date in the research project. This modest investigation of nutrient dynamics for the SE Bering Sea shelf analyzed samples from late winter to ascertain pre-spring bloom nutrient conditions. The follow up spring bloom cruise (MF 99-06) occurred as water column stratification increased to support enhanced phytoplankton utilization of nutrients. The preliminary conclusion from the data is that the nutrient concentrations and supporting physical conditions for late spring and early summer 1999 were closer to typical than 1997 or 1998. Subsequent nutrient analyses on the cooperative Inner Fronts project confirmed that nutrient availability and plankton responses were much more typical that the previous two years. Editing of the 1999 nutrient data is not complete but will be accomplished when CTD data becomes available.

SCIENTIFIC ACCOMPLISHMENTS

Over the past year a major effort has been to describe unusual conditions observed during 1997 and 1998. The two very different years in terms of the distribution of properties heavily influenced nutrient distributions and utilization. Significant new insight into the productivity effects that occur when the euphotic zone becomes much deeper than the mixed layer depth was attained from both 1997 and 1998. The unusual conditions were likely responsible for an unusual coccolithophorid bloom that has persisted for the past three years. The unusually warm, stable upper water column was impoverished for nutrients which was poor for diatom growth but favored the slow growing coccolithophorids. The collection of nutrients in water samples has also improved the analysis of in situ nitrate concentrations at mooring site 2 which is a new project that was started in February 1999.

APPLICATIONS

Publications

Coachman, L.K., T.E. Whitledge and J.J. Goering. (In press). Silica in Bering Sea deep and bottom water. In: T.R. Loughlin and K. Ohtani (editors), The Bering Sea: Physical, Chemical and Biological Dynamics, Univ. Of Alaska Sea Grant, Fairbanks, Alaska.

Hunt, G.L., C.L. Baduini, R.D. Brodeur, K.O. Coyle, N.B. Kachel, J.M. Napp, S.A. Salo, J.D. Schumacher, P.J. Stabeno, D.A. Stockwell, T.E. Whitledge and S.I. Zeeman. (In press). The Bering Sea in 1998: A second consecutive year of extreme weather-forced anomalies. Eos

Hunt, G.L., C.L. Baduini, K.O. Coyle, J.M. Napp, J.D. Schumacher, P.J. Stabeno, D.A. Stockwell, T.E. Whitledge and S.I. Zeeman. (submitted). Rapid responses of the

southeastern Bering Sea shelf ecosystem to variation in weather patterns in 1997 and 1998. Proceedings of the National Academy of Sciences.

Stockwell, D.A., T.E. Whitledge, S.I. Zeeman, K.O. Coyle, J.M. Napp, R.D. Brodeur and A.I. Pinchuk. (submitted) Anomalous conditions in the southeastern Bering Sea, 1997: Nutrients, phytoplankton, and zooplankton. Fish. Oceanogr.

Whitledge T.E. and V.A. Luchin. (In press). Summary of chemical distributions and dynamics in the Bering Sea. In: T.R. Loughlin and K. Ohtani (editors), The Bering Sea: Physical, Chemical and Biological Dynamics, Univ. Of Alaska Sea Grant, Fairbanks, Alaska.

Presentations at Meetings

Hunt, G.L., C.L. Baduini, R.D. Brodeur, K.O. Coyle, N.B. Kachel, J.M. Napp, S.A. Salo, J.D. Schumacher, P.J. Stabeno, D.A. Stockwell, T.E. Whitledge and S.I. Zeeman. The Bering Sea in 1998: A second consecutive year of extreme weather-forced anomalies. The Oceanography Society Meeting, August 1999, Reno, Nevada. (Oral Presentation)

Hunt, G.L., C.L. Baduini, R.D. Brodeur, K.O. Coyle, J.M. Napp, J.D. Schumacher, P.J. Stabeno, D.A. Stockwell, T.E. Whitledge and S.I. Zeeman. Ecosystem responses of the southeastern Bering Sea to abnormal weather patterns in 1997 and 1998. International Council of the Exploration of the Sea, September 1999, Denmark. (Oral Presentation)

Napp, J.M., J.J. Goering, S. Henrichs, T.K. Rho, T.E. Whitledge, C.T. Baier, R.D. Brodeur, D.M. Blood, J.J. Cullen, R.F. Davis, J.D. Schumacher, P.J. Stabeno, G.L. Hunt and G.L. Swartzman. Southeast Bering Sea Carrying Capacity (SEBSCC): Ecosystem dynamics research in a marginal sea. North Pacific Marine Science Organization (PICES) Seventh Annual Meeting, 14-25 October 1998, Fairbanks, Alaska. (Oral Presentation)

Stockwell, D.A. and T.E. Whitledge. Apparent nutrient/phytoplankton responses to unusual physical conditions in the southeast Bering Sea during 1997-1998. American Society of Limnology and Oceanography Meeting, February 1999, Santa Fe, New Mexico. (Poster)

Whitledge, T.E. Bering Sea nutrient dynamics: Then and Now. FOCI International Workshop on Recent Conditions in the Bering Sea. 9-10 November 1998, Seattle, Washington. (Invited Oral Presentation)

Whitledge, T.E. Recent productivity changes in the Bering Sea and implications for the Arctic Ocean during climate change. Biogeochemical Processes in the Arctic Ocean Workshop,

International Arctic Research Center, 28-30 March 1999, Fairbanks, Alaska. (Invited Oral Presentation)

Whitledge, T.E. and D.A. Stockwell. Deep phytoplankton uptake and growth on the Southeast Bering Sea shelf in 1997 and 1998. North Pacific Marine Science Organization (PICES) Seventh Annual Meeting, 14-25 October 1998, Fairbanks, Alaska. (Oral Presentation)

STEPS TO COMPLETION

1. Nutrients on early 2000 Miller Freeman mooring cruise and nitrate in situ sensor (NISS) recovery/deployment
2. Nutrients on spring Ron Brown cruise
3. Nutrients on early summer Miller Freeman eddy cruise funded by NPMR
4. Nutrients on summer Alpha Helix plankton processes cruise funded by NPMR
5. Nutrients on fall mooring recovery cruise and NISS recovery/deployment

The physical and biological processes that drive nutrient dynamics of the SE Bering Sea shelf have been observed over the past three by the SEBSCC program. The increasing length of data records have improved our understanding of nutrient processes and their coupling to primary production within the context of seasonal and interannual variability. It is a high priority of this research to continue to understand the physical processes that are responsible for supporting primary production processes.

TITLE: Sinking organic matter and pelagic food webs

PRINCIPAL INVESTIGATOR

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PARTICIPATING INVESTIGATOR

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OBJECTIVES AND METHODS

The project objective is to test the hypothesis that the temporal variation of the quantity and composition of sinking particles depends on the on-shelf transport of nutrients, because of the impact of nutrient availability on the productivity and species composition of pelagic primary and secondary producers. Since the composition of the sinking organic matter reflects the pelagic food web, the research will improve understanding of primary production and of the transfer of water column production to the benthos. This project is a continuation of SEBSCC research begun in 1996, but this report focuses on new sampling and analyses during Phase II, beginning in October 1998.

Moored sediment traps are being used to examine temporal variability, on time scales of weeks to years, in the source and quantity of sinking particles. The sediment trap samples have been analyzed for carbon and nitrogen stable isotope composition. The stable isotope composition of sinking particles is expected to reflect the rate of photosynthesis, extent of nutrient depletion, and the trophic level of animals supplying particulate matter to the trap. The stable isotope composition of zooplankton collected near the mooring sites is also being determined.

One trap was deployed in mid-October, 1998, at site M2 (56°53' N, 164°02' W), and successfully recovered in February 1999. Two sediment traps were deployed at M2 and M3 (56°04' N, 166°20' W) in February 1999, and were recovered in late September 1999. Plankton samples

were collected at the five "X" stations near sites M2 and M3 in February and September, 1999, and near M2, M3, and M4 (57°52' N, 169°12'W) during April and May, 1999.

RESULTS AND DISCUSSION

During 1999 the isotopic analyses of the 1998 sediment trap and zooplankton samples were completed. Also, isotopic analyses of plankton samples collected during 1999 were done. Comparison of the 1997 and 1998 data revealed several interesting patterns:

- The organic material collected by the sediment traps had a greater $\delta^{15}N$ from May through August during 1997 than during 1998. This difference was also seen in the isotopic composition of the zooplankton collected at this site during 1997 and 1998. It probably reflects the strong stratification and nutrient depletion of surface waters that occurred during spring and summer of 1997.

- Most dates had similar $\delta^{13}C$ during 1997 and 1998, but the sediment trap samples were about 1‰ lighter during June 1997 than in June 1998. June 1997, was an extremely calm, strongly stratified period, and the unusually low $\delta^{13}C$ values may reflect low primary productivity due to nutrient limitation.

- During 1998 M3 sediment trap samples had consistently lower $\delta^{15}N$ and $\delta^{13}C$ than M2 samples. These differences in isotopic composition were also seen in copepods collected at these two sites. The $\delta^{15}N$ difference could reflect less nutrient depletion at the outer shelf site, and the $\delta^{13}C$ difference lower primary productivity at M3.

- Figure Hen-1 shows the temporal variation in copepod and euphausiid $\delta^{15}N$ at sites M2 (along with M4, another middle shelf station) and M3 through May 1999. The values in 1997 are highest, again reflecting strong stratification and nutrient depletion. In both 1998 and 1999 there is a decrease in $\delta^{15}N$ in April-May, associated with the spring bloom; this was not seen in 1997.

PUBLICATION

Smith, S. and S. M. Henrichs. Submitted. Interannual and geographic variability in sinking particles over the southeastern Bering Sea shelf. 2000 Ocean Sciences Meeting.

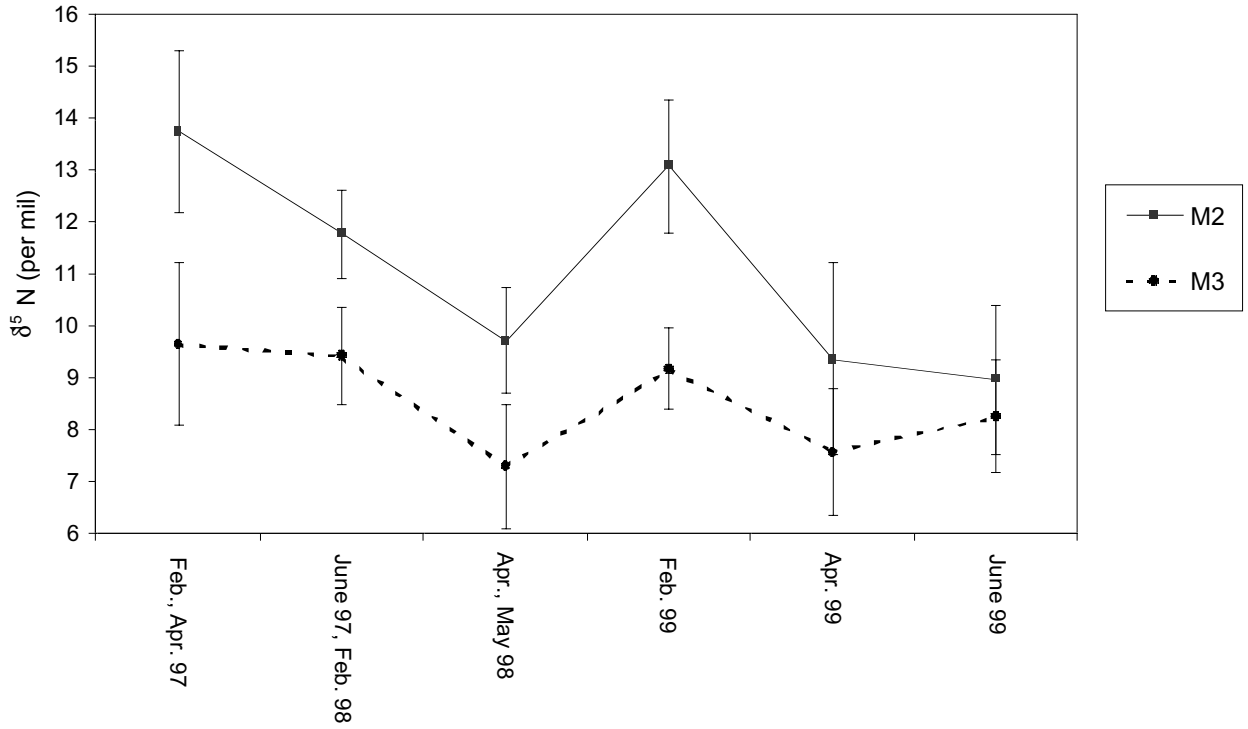

Figure Hen-1. Temporal variation of the $\delta^{15}N$ of copepods and euphausiids collected at sites M2 and M3 over the southeastern Bering Sea shelf. Error bars are ± 1 standard deviation.

TITLE: In situ monitoring of nitrate concentrations

PRINCIPAL INVESTIGATOR

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GOALS AND OBJECTIVES

The objective of this research is to continuously monitor the temporal variability in the concentration of nitrate at mooring site 2 through two annual cycles and identify mechanisms that determine replenishment of nutrients.

PROGRESS

The primary task to accomplish the objective was to deploy the nitrate in situ sensor (NISS). The first deployment was accomplished as planned on MF 99-01 cruise in February 1999. The instrument was calibrated before deployment and CTD/rosette samples were collected to cross check calibrations. The mooring was recovered in April 99 and the in situ standard solutions were analyzed as a post recovery calibration. The lack of a second instrument prevented redeployment in April so the NISS was deployed again in Sept 99 with a planned duration of six months.

SEBSCC Mooring Recovery/Deployment Cruises:

MF 99-01 Feb 99	Miller Freeman	Deployed at mooring 2
MF 99-04 April 99	Miller Freeman	Recovered mooring 2
MF 99-12 Sept 99	Miller Freeman	Deployed at mooring 2

Other Cooperative Program: (Pending) CIFAR/IARC Nitrate Moorings

MF 00-04 April 00	Miller Freeman	Moorings 3 & 4
MF 00-09 Sept 00	Miller Freeman	Moorings 3 & 4

SCIENTIFIC ACCOMPLISHMENTS

The February 1999 deployment of NISS was the first known successful deployment in open ocean shelf waters. In addition, this was the first deployment in subzero waters. This initial set of nitrate data will be combined with temperature, salinity and fluorescence records to produce the first complete physical/biological data set during the start of the spring bloom.

APPLICATIONS: None to date.

STEPS TO COMPLETION

1. Deployment of NISS will occur on the September 1999 Miller Freeman cruise

2. Recovery/deployment of NISS will occur on the early 2000 Miller Freeman mooring cruise

3. Deployment of NISS at mooring sites 3 and 4 in April 2000 if CIFAR/IARC is funded.

4. Recovery/deployment at mooring sites 2, 3 and 4 in September 2000.

The physical and biological processes that drive nutrient dynamics of the SE Bering Sea shelf have been observed with only water samples over the past three years by the SEBSCC program.

The NISS moorings in conjunction with the physical moorings will greatly enhance the ability to elucidate the major physical processes causing nutrient enrichment of shelf waters. The increased length much higher temporal resolution of data records will greatly improve our understanding of nutrient processes and their coupling to primary production within the context of seasonal and interannual variability. It is a high probability of this research to continue to improve our understanding of the physical processes that are responsible for supporting primary production processes.

TITLE: Proximity of age-0 pollock, jellyfish, predators and prey

PRINCIPAL INVESTIGATORS

Gordon L Swartzman, University of Washington

Kenneth Coyle, University of Alaska Fairbanks

Richard D. Brodeur and Jeffrey M. Napp, National Marine Fisheries Service, Alaska Fisheries Science Center

COLLABORATORS

D. Van Holliday, Marconi Corp

Andreas Winter, University of Washington

GOALS AND OBJECTIVES

The main thrust of this research project is to examine the basis for year-class strength of pollock in the neighborhood of the Pribilof Islands by synthesizing acoustic survey data collected over six years (1994-1999) at several frequencies (allowing simultaneous identification of fish shoals and zooplankton patches), with trawl net sampling and environmental data. We also hope to test the plankton patch identification algorithm through directed comparison of acoustic predictions with MOCNESS net samples collected on the 1999 survey.

PROGRESS

Work during our Phase II SEBSCC project has focussed on processing acoustic data from the 1997 and 1998 Pribilof Island September surveys, developing methods for evaluation of our algorithm for plankton identification, and participating in data collection on the 1999 Pribilof Island September survey. To this end we have:

Extracted and processed acoustic data from the 1997 and 1998 surveys and produced maps of fish shoal and plankton patch distribution along the four study transects (A, B, C and D; Figure Swar-1).

Combined the acoustic data with bottom depth and temperature profiles along the transects.

Participated in an initial workshop with D. Van Holliday to discuss our net-acoustics comparison methods, and how best to use a 4-frequency acoustic system for the 1999 survey to better distinguish size classes of plankton in the acoustic images.

Consulted with Dr. Timothy Stanton (Wood Hole Oceanographic Institute) on proper computation of backscatter from various zooplankton taxa using his “forward” equations. These equations will allow us to estimate backscatter expected from the plankton obtained in net samples for comparison with acoustic predictions.

Participated in design and implementation of the research protocol for the 1999 survey. This survey featured day and night transect runs of two focus transects (A and D; Figure Swar-1) with both a two frequency hull mounted EK-500 system (38 and 120 kHz) and a four frequency towed body mounted HTI system (43, 120, 200 and 420 kHz). We also conducted 48-hour diel studies at two stations on transect A.

Because of the very high and pervasive fish abundance this year on Transect A in 1999, we judged the zooplankton abundance was either too low or inseparable from the fish to allow evaluation of the plankton identification algorithm. Therefore we conducted directed comparisons of net sampling with acoustics at locations along transects B and C (Figure Swar-1), where earlier transect runs with the acoustic systems revealed the presence of probably large patches of zooplankton.

Participated in observation of birds along the study transects during 1999 daytime transect runs.

We have also conducted research in collaboration with SEBSCC scientists on *the Habitat Differences* project. These include

Provide acoustic data on pollock and plankton abundance for use in the energetics modeling project (Lorenzo Ciannelli).

Participated in analysis of acoustic data from a 1996 48-hour diel study at a site on transect A.

Began analysis of acoustic survey data collected during the NMFS MACE cruise in summer 1996. With these acoustic data we hope to compare the relative abundance of pollock and zooplankton during July and September 1996 with an eye to testing the hypothesis that the zooplankton abundance was severely reduced by September through grazing by the large pollock biomass in the area (Schabetsberger, Ciannelli, Brodeur).

Worked on examining the proximity of clusters of piscivorous birds (murres and puffins) along the study transects in 1994-1997 and fish shoal abundance below the clusters and revising a manuscript on this work (George Hunt).

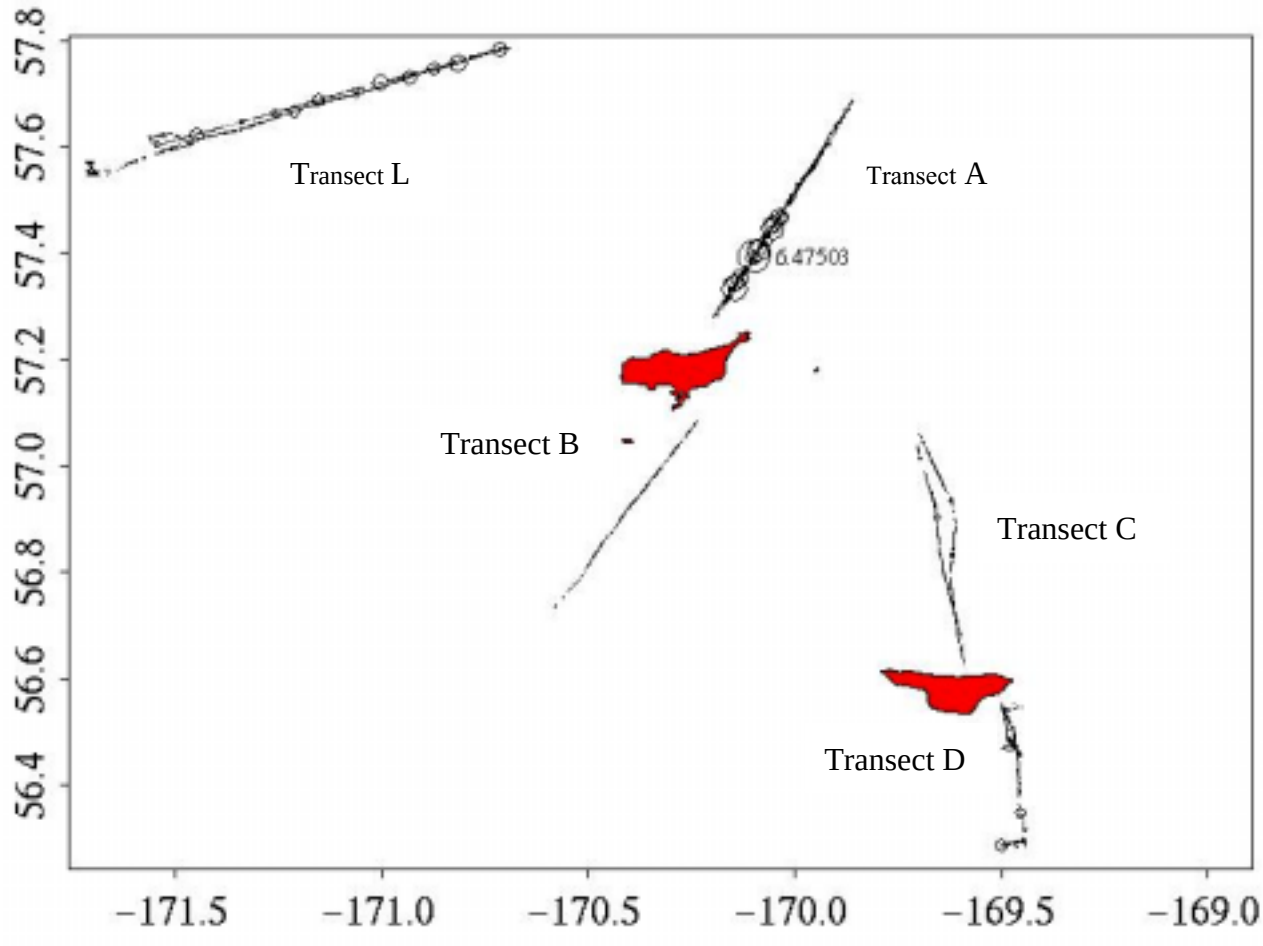

Figure Swar-1. Transects covered in 1994-1999 September surveys near the Pribilof Islands, AK. Fish abundance along the transects in 1995 is shown by circles proportional to shoal biomass.

SCIENTIFIC ACCOMPLISHMENTS

With completion of the 1999 survey, we now have data from six September cruises along the same transects in the Pribilof Islands. We have already completed a comparison of the 1994 and 1995 survey data (see Phase I SEBSCC final report), with emphasis on 1) methods developed to separate fish from plankton from multi-frequency acoustic backscatter data; and 2) the proximity of fish and plankton during these years and their relationship to plankton abundance. We are beginning to compare all six survey years, combining acoustic, net environmental and bird observation data to improve our understanding of the factors which influence year-class-strength

of pollock during in an important nursery area for pollock. Much of our work in phase II has involved processing and visualizing acoustic data from 1997 and 1998 (Fig. Swar-2) and preparing and conducting sampling in 1999. Based on pollock abundance, the years can be

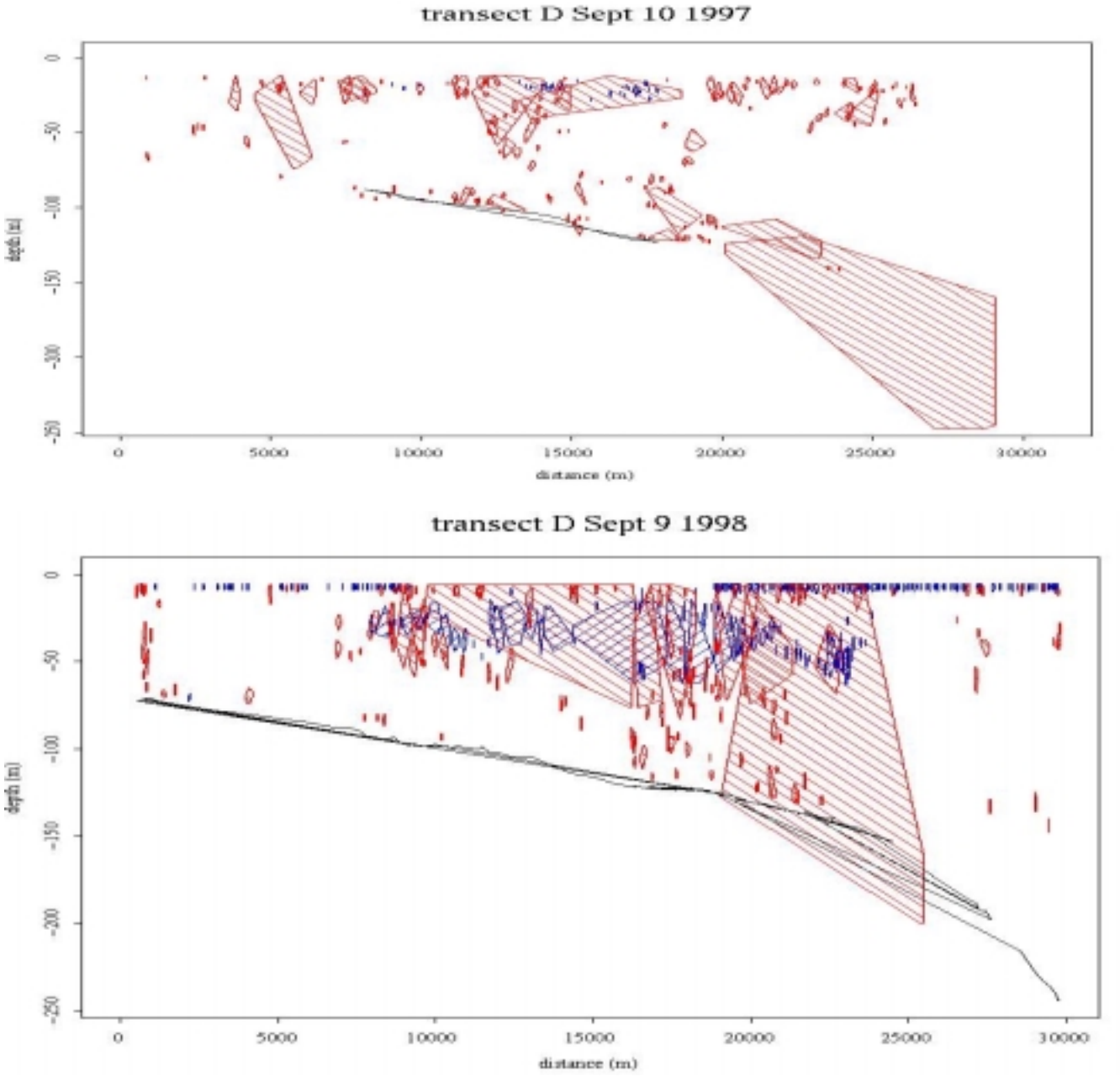

Figure Swar-2. A comparison of results of acoustic data analysis for nighttime transect D for 1997 and 1998. Fish shoals are shown by blue polygons and plankton patches by red polygons.

conveniently grouped into years of high fish and low plankton abundance (1996 and 1999), low fish and high plankton (1997) and intermediate levels of fish and plankton (1994, 1995 and 1998). Our synthesis thus far has emphasized the acoustic data and environmental data, such as the depth of the thermocline and surface temperature. However, we are starting to also examine data on the size distribution of fish at different depths (from anchovy trawls), juvenile pollock diet information (from gut samples taken during anchovy and Methot trawls) and compare this to the acoustic data.

We have spent considerable time reviewing and implementing methods for comparing net samples of zooplankton to volume scattering in the acoustic backscatter images at different frequencies. This review is preparatory to the MOCNESS sample-acoustic data comparison using acoustic data like that previously collected (the EK-500 system), but also the HTI 4-frequency system deployed during the 1999 survey (by Dr. Kenneth Coyle). Among the techniques considered for identifying size classes of plankton and distinguishing them from fish are 1) combining morphological images processing and image differencing to identify patches in different size ranges and using the forward equation, calibrated to plankton found in MOCNESS hauls, to ascribe size/functional groups to the different patches; 2) Canonical correlation to relate MOCNESS haul plankton to acoustic backscatter at different frequencies; 3) an inversion technique combined with forward equations to calibrate the MOCNESS and acoustic data (Fig. Swar-3).

APPLICATIONS

Publications resulting from this project

Schabetsberger, R., RD Brodeur, L. Ciannelli, J.M. Napp, and G.L. Swartzman. MS. Diel vertical migration and interaction of zooplankton and micronekton at a frontal region near the Pribilof Islands, Bering Sea. (Submitted to ICES Journal of Marine Science).

Swartzman, G., RD Brodeur, J.M. Napp, D. Walsh, R. Hewitt, D. Demer, G. Hunt, and E. Logerwell. 1999. Relating predator and prey spatial distributions in the Bering Sea using acoustic backscatter data. Can. J. Fish. Aquat. Sci. (in press)

Swartzman, G., R. Brodeur, J.M. Napp, G. Hunt, D. Demer, and R. Hewitt. 1999. Spatial proximity of age-0 walleye pollock to their plankton prey near the Pribilof Islands, Bering Sea, Alaska. ICES Journal of Marine Science. 56:23-41

Swartzman, G. L. and G. Hunt. 1999. Spatial association between murres (Uria spp), puffins (Fratercula spp) and fish shoals near the Pribilof Islands, Alaska. (resubmitted to Marine Ecology Progress Series).

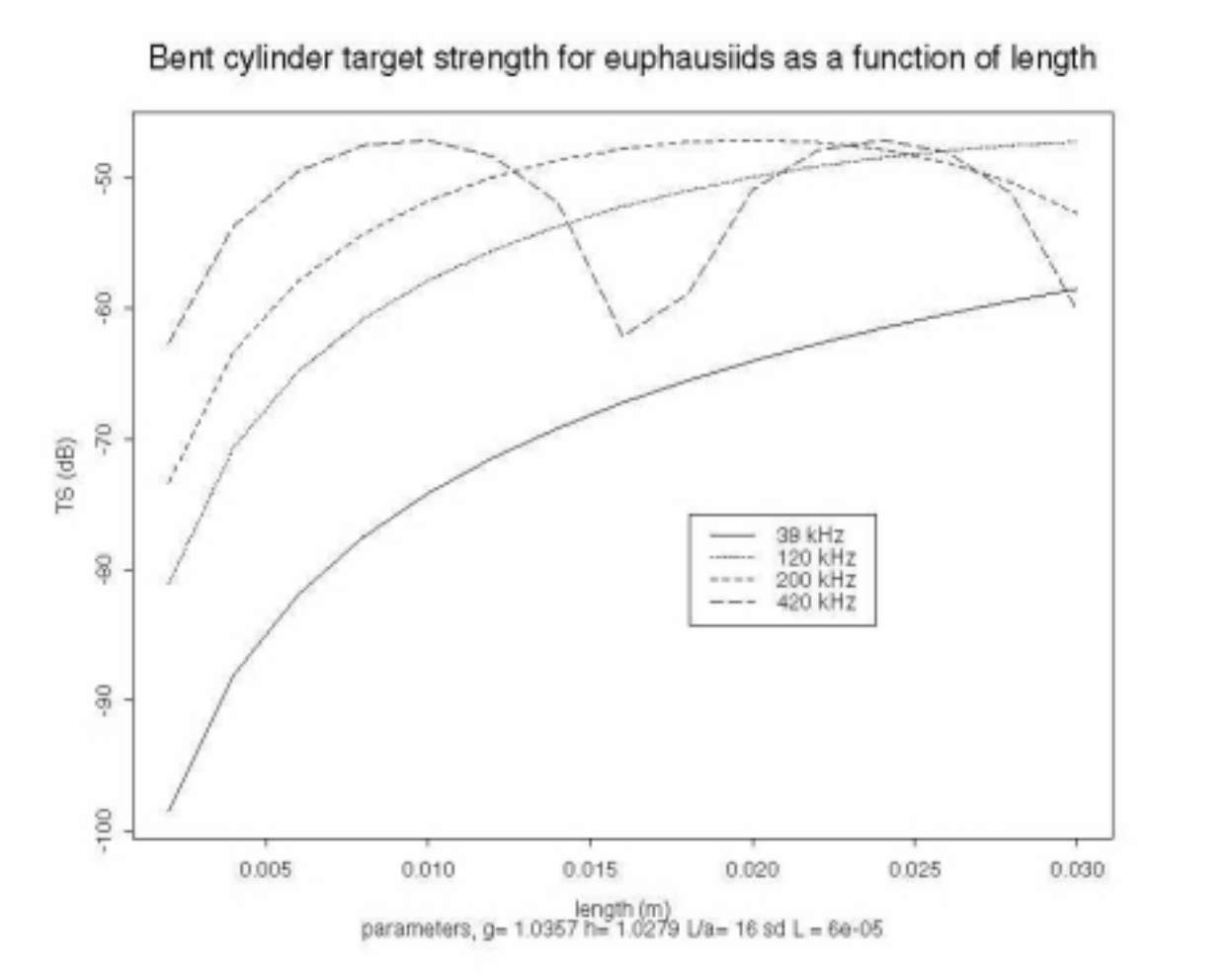

Figure Swar-3. Results from a geometric forward equation (from Stanton and Chu 1995) showing predicted backscatter (dB) as a function of length from an individual euphausiid at four frequencies. The euphausiid is modeled as a bent cylinder.

Presentations at meetings

April 1999. Plankton-fish spatial proximity near the Pribilof Islands, AK. Presented at annual ICES working group on Fisheries Acoustic Science and Technology, in St. Johns, Newfoundland, Canada (Swartzman, Brodeur, Napp, Hunt, Demer, Hewitt). This was a poster, which is provided here:..\..\ices\probilof.ppt

June 1999. Spatial association between murres (*Uria* spp.), puffins (*Fratercula* spp.) and fish shoals near the Pribilof Islands, Alaska (Swartzman, Hunt) presented at International Symposium on Natural Resource Modeling in Halifax, Nova Scotia. This was a PowerPoint presentation..\bird.paper.rma.ppt

STEPS TO COMPLETION

Our major challenge over the next couple of years will be teaming with researchers on other projects (Habitat, modeling, monitoring) to both acquire additional data for synthesis and conducting the synthesis. We are also committed to continuing our testing of the multi-frequency algorithm for identifying zooplankton patches. We envision the following efforts and collaborations:

Conduct a workshop on methods for plankton identification. This is currently planned for the end of January 2000. Participants include Drs. Swartzman, Napp, Holliday and Coyle, with additional participation by graduate students (Ciannelli and Winter). Follow up on the workshop will involve processing of the 1999 survey data for plankton identification using the best method available (assuming we find one that is adequate).

Compare the distribution of plankton with diets of juvenile pollock to consider whether pollock are selective in their diets and how the selection relates to pollock size and proximity to plankton.

Compare the abundance and proximity of fish and plankton between all six survey years, with an eye to changes in relative abundance pattern and its influence on proximity and growth. This will be done in collaboration with the SEBSCC habitat project. We will also examine how different conditions influenced pollock year class strength.

Help with analysis of the acoustic data for the two diel studies conducted on transect A in 1999 particularly to look at the time phasing of diel migration of both fish and plankton and their influence on the timing of pollock feeding. Preliminary results suggested that, on transect A in 1999 there were two layers of pollock during the daytime, with larger pollock (50-80mm) above the thermocline and smaller pollock (20-45 mm) above the thermocline. These two layers mixed in the upper water column during the daytime. We will compare differences in diet and feeding of these two young-of -the -year size cohorts with their depth distribution.

We will examine bird cluster distributions, adding planktivorous birds (auklets, murrelets and shearwaters), and compare these to the distribution of plankton and fish in the upper water column (above the thermocline). This will be more possible in 1999 when we had a 4-frequency system, which also had access to backscatter closer to the surface than the EK-500 system.

TITLE: Habitat differences in frontal regions around the Pribilof Islands and their importance to juvenile pollock growth and survival in the Bering Sea

PRINCIPAL INVESTIGATORS: Richard D. Brodeur, Jeffrey M. Napp, and A.J. Paul

COLLABORATORS: Matthew T. Wilson, Lorenzo Ciannelli, and Robert C. Francis

PROGRESS

In July of 1998 and 1999, we sampled the southeastern Outer and Middle Shelf Domains, including the Pribilof Islands during a collaborative research cruise aboard the Hokkaido University research vessel *Oshoro Maru.* The same core group of stations was sampled both years that had been sampled since 1995. Juvenile pollock catches were relatively low in 1998 but substantially higher in 1999. In September of 1998, we conducted a 12 day cruise in aboard the chartered Russian research vessel *Professor Kaganovsky*. We were able to successfully complete all our sampling although we were not able to accomplish as much as we normally do on the *Miller Freeman* due to technical and logistic difficulties. All the fish catch data have been entered into our database and the plankton and micronekton samples have been sorted and identified and are back in Seattle. In September 1999, we again sampled the habitats around the Pribilof Islands using the *Miller Freeman.* This cruise was still in progress at the time of the writing of this report so we have no results to provide at this time. Early indications are that juvenile pollock are very abundant around the Pribilof Islands in 1999, especially along Line A, and perhaps are as abundant as in 1996, the previous high year of abundance.

SCIENTIFIC ACCOMPLISHMENTS

A poster on the results of our research was presented at the PICES annual meeting in Fairbanks in October 1998 which outlines the progress made in several of our studies relating frontal structure to juvenile distribution, growth and ecology. This poster can be viewed at the following URL: http://www.pmel.noaa.gov/programs/review98/fronts.jpg.

We are continuing the work on this project and hope to have a paper available by the end of next year on a 3-year comparison of the fish catches and feeding and growth of juvenile pollock in relation to oceanographic conditions.

We are also examining the Methot trawl catches for habitat differences in fish and macrozooplankton along Lines A and D. We have completed a study of the diel variability in zooplankton and juvenile pollock distributions and the feeding selectivity of pollock at a single

location. The results of this study were presented at the February Ocean Sciences meeting and a manuscript has been submitted to ICES Journal of Marine Science.

The research done by our University collaborators has not progressed as far due to the fact that A.J. Paul at the University of Alaska did not receive his COP funding until August 26, 1999 -- almost a year after the award was made. However, up to the present time we have: 1) retrieved the archived somatic energy storage samples from the FOCI sample bank, 2) transferred the frozen samples to Seward for analysis, 3) selected the samples to analyze [There were 7 stations from 1994 with enough YOY pollock for a good sample; 9 stations from 1995, and 18 stations from 1996], and 4) started the calorimetric analysis of the 1994 samples.

The University of Washington modeling component of this study also was delayed in receiving funding until about the same time so progress on this part of the study has been hampered. Some modeling has been done and food consumption and growth potential maps for 1994 through 1996 have been completed. A paper on this was presented at the 1998 Ocean Sciences meeting and will also be presented at the 1999 Lowell Wakefield Symposium on spatial processes in Anchorage during October.

Another side project completed was the analysis of fish and zooplankton aggregations in Pribilof Canyon south of St. George Island. Although it turned out that juvenile pollock were not common in this canyon, there were large swarms of offshore euphausiids that were advected up the canyon where they were preyed upon by rockfishes. This study utilized trawl catches, acoustic measurements, and in situ underwater observations to examine these relationships. A manuscript documenting this was completed and will be submitted shortly.

In November 1998, Ric Brodeur and Jeff Napp co-organized an international workshop on recent conditions in the Bering Sea held in Seattle. About a hundred scientists, managers, and policy makers from across the U.S., Canada, Russia, and Japan attended this two-day workshop. Jeff was in charge of the lower trophic level session and Ric was in charge of the fish and fisheries section. The proceedings of the workshop were published in a ERL special volume to which several of our investigators contributed.

APPLICATIONS

Publications resulting from this project

Brodeur, R.D. MS. Habitat-specific distribution of Pacific Ocean perch (*Sebastes alutus*) in Pribilof Canyon, Alaska. (To be submitted to *Continental Shelf Res.*).

Brodeur, R.D., G.H. Kruse, P.A. Livingston, G. Walters, J. Ianelli, G.L. Swartzman, M. Stepanenko, and T. Wyllie-Echeverria. 1999. Living marine resources (Groundfish, Salmon, and Crabs). NOAA ERL Spec. Rep. On the FOCI International Workshop on Recent Conditions in the Bering Sea, pp. 21-26.

Brodeur, R.D., C.E. Mills, J. Overland, G.E. Walters, and J. D. Schumacher. In press. Evidence for a substantial increase in jellyfish in the Bering Sea, with possible links to climate change. *Fish. Oceanogr*. 9(1).

Brodeur, R.D. and M.T. Wilson. 1999. Pre-recruit walleye pollock in the Eastern Bering Sea and Gulf of Alaska Ecosystems. Proceedings of GLOBEC International Marine Science Symposium on Ecosystem Dynamics, pp 238-251.

Brodeur, R.D., M.T. Wilson, and L. Ciannelli. 1999. Spatial and temporal variability in feeding and condition of age-0 walleye pollock in frontal regions of the Bering Sea. *ICES J. Mar. Sci.* 56.

Brodeur, R.D., M.T. Wilson, G.E. Walters, and I.V. Melnikov. 1999. Forage fishes in the Bering Sea: Distribution, species associations, and biomass trends. In: Loughlin, T.R. and K. Ohtani (eds.) *The Bering Sea: Physical, Chemical, and Biological Dynamics*. Univ. of Alaska Sea Grant.

Hunt, G.L. Jr., C.L. Baduini, R.D. Brodeur, K.O. Coyle, N.B. Kachel, J.M. Napp, S.A. Salo, J.D. Schumacher, P.J. Stabeno, D.A. Stockwell, T.E. Whitledge, S.I. Zeeman. In press. The Bering Sea in 1998: A second Consecutive Year of Extreme Weather-forced Anomalies. *EOS*.

Lang, G.M., R.D. Brodeur, J.M. Napp, and R. Schabetsberger. 1999. Variation in groundfish predation on juvenile walleye pollock relative to hydrographic structure near the Pribilof Islands, Alaska. *ICES J. Mar. Sci*. 56.

Napp, J.M., R.D. Brodeur, D. Demer, R. Hewitt, P.J. Stabeno, G.L. Hunt, and J.D. Schumacher. MS. Observations of nekton, zooplankton, and seabird distributions at tidally generated shelf fronts in the eastern Bering Sea. (Submitted to *Mar. Ecol. Prog. Ser*.).

Napp, J.M., K.O. Coyle, T.E. Whitledge, D.E. Varela, M.V. Flint, N. Shiga, D.M. Schell, and S.M. Henrichs. 1999. Nutrients and lower trophic level response. NOAA ERL Spec. Rep. On the FOCI International Workshop on Recent Conditions in the Bering Sea, pp. 13-20.

Napp, J.M. and G.L. Hunt, Jr. MS. Anomalous conditions in the southeastern Bering Sea, 1997: Linkages among climate, weather, ocean, and biology. (Submitted to *Fish. Oceanogr*.).

Schabetsberger, R., R.D. Brodeur, L. Ciannelli, J.M. Napp, and G. Swartzman. MS. Diel vertical distribution and interaction of fish and plankton and a frontal region of the Bering Sea. (Submitted to *ICES J. Mar. Sci*.).

Stockwell, D.A., T.E. Whitledge, S.I. Zeeman, K.O. Coyle, J.M. Napp, R.D. Brodeur and A.I. Pinchuk. MS. Anomalous conditions in the southeastern Bering Sea, 1997: Nutrients, phytoplankton, and zooplankton. (Submitted to *Fish. Oceanogr*.).

Swartzman, G., R.D. Brodeur, J.M. Napp, G.L. Hunt, D. Demer, and R. Hewitt. 1999. Spatial proximity of age-0 walleye pollock (*Theragra chalcogramma*) to zooplankton near the Pribilof Islands, Bering Sea, Alaska. *ICES J. Mar. Sci*.

Presentations at Scientific Meetings

October 1998- Forage fishes in the Bering Sea: Distribution, species associations, and biomass trends. REX workshop on Small Pelagics, Fairbanks, Alaska (Brodeur Wilson, Walters, and Melnikov).

October 1998- Fronts and Fish: Interannual and regional differences in frontal structure and effects on pollock and their prey. PICES Annual Meeting (Brodeur, Doyle, Napp, Stabeno, Salo, and Wilson).

October 1998- Evidence for a recent increase in jellyfish in the Bering Sea, with possible links to climate change. PICES Annual Meeting (Brodeur, Mills, Overland, and Walters).

November 1998 – Nutrients and lower trophic level response. International Workshop on Recent Conditions in the Bering Sea. (Napp, J.M. and seven coauthors).

February 1999 - Are recent eastern Bering Sea ecosystem anomalies early evidence for climate change? What do records of zooplankton biomass and species composition tell us? American Society of Limnology and Oceanography meetings, Santa Fe, NM, (Napp, J.M., Brodeur, R.D., Schumacher, J.D., Stabeno, P.J., and Jorgensen, E.M).

February 1999- Bioenergetics of age-0 walleye pollock in a frontal structure of the Bering Sea. ASLO Aquatic Sciences Meeting, Santa Fe, NM. (L Ciannelli and R. Brodeur).

February 1999- Diel vertical migration, feeding selectivity, and prey distribution of juvenile walleye pollock at a productive frontal region in the Bering Sea. ASLO Aquatic Sciences Meeting, Santa Fe, NM. (R. Schabetsberger, R. Brodeur and J. Napp).

March 1999- Has the carrying capacity of the North Pacific changed in recent decades? Workshop on Ocean-Climate Change and Variability in Fish Recruitment. Anchorage, AK (R. Brodeur, W. Pearcy and K. Aydin).

STEPS TO COMPLETION

1. Complete analysis of interannual variation in biophysical conditions in each of the habitats with respect to survival of juvenile pollock.

2. Examine diets of juvenile pollock from anomalous years of coccolithophore blooms (1997 and 1998).

3. Examine interannual variation in condition of pollock and relate this to past otolith growth analysis.

4. Continue spatially explicit modeling of juvenile pollock and their prey.

5. Estimate food consumption and growth potential for all years of sampling.